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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

...erage 1 hour per response, including the time for reviewing instructions, searching existing data sources ... the collection of information. Send comments regarding this burden estimate or any other aspect of this ... Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson ... Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY	2. REPORT DATE 07/00/83	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
QUANTITY OF SURFACE WATER RUNOFF FROM SOUTH PLANTS AREA WATERSHEDS ON ROCKY MOUNTAIN ARSENAL

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ROCKY MOUNTAIN ARSENAL (CO.)
COMMERCE CITY, CO

8. PERFORMING ORGANIZATION REPORT NUMBER
84132R01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

DTIC ELECTE NOV 1 0 1994 S G D

258

94-34874

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

THIS REPORT IS A STUDY CONDUCTED OF THE SOUTH PLANTS CHEMICAL MANUFACTURING AREA ON ROCKY MOUNTAIN ARSENAL TO DETERMINE THE QUANTITY OF WATER LEAVING THE AREA AS SURFACE RUNOFF. SINCE THE SOUTH PLANTS WERE ORIGINALLY CONSTRUCTED OVER A HIGH POINT ON THE ARSENAL, SURFACE WATER RUNOFF FLOWS IN MANY DIRECTIONS FROM THE SITE. TEN WATERSHEDS WERE IDENTIFIED IN THE SOUTH PLANTS AREA AND SEPARATE CALCULATIONS WERE CONDUCTED FOR EACH WATERSHED. DESIGN STORMS REPRESENTING A 24 HOUR PRECIPITATION EVENT WITH RETURN FREQUENCIES OF 2, 5, 20, 25 AND 100 YEARS WERE USED TO DETERMINE THE TOTAL VOLUME OF RUNOFF AND THE MAXIMUM FLOW RATE THAT COULD OCCUR FROM THE PLANTS WATERSHEDS. THE FLOW AND VOLUME CALCULATIONS FOR THE SOUTH WATERSHEDS TAKE INTO CONSIDERATION THE EFFECTS OF EXISTING STORM SEWER NETWORKS.

14. SUBJECT TERMS
RAIN FALL DATA, RUNOFF

94 11 9 044

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED			

→ KIC

84132R01
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QUANTITY OF SURFACE WATER RUNOFF FROM SOUTH PLANTS AREA WATERSHEDS ON ROCKY MOUNTAIN ARSENAL

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Ron Gregg

Management Systems Control Office

Directorate of Technical Operations

Rocky Mountain Arsenal

JULY 1983

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INTRODUCTION

A study was conducted of the South Plants chemical manufacturing area on the Rocky Mountain Arsenal to determine the quantity of water leaving the area as surface runoff. Since the South Plants were originally constructed over a high point on the Arsenal, surface water runoff flows in many directions from the site. Ten watersheds were identified in the South Plants area and separate calculations were conducted for each watershed. Design storms representing a 24 hour precipitation event with return frequencies of 2, 5, 10, 25 and 100 years were used to determine the total volume of runoff and the maximum flow rate that could occur from the plants watersheds. The flow and volume calculations for the south watersheds take into consideration the effects of the existing storm sewer network.

WATERSHED MAPPING

Watersheds in the the South Plants area were mapped using the Shell Chemical Company surface drainage system map, an Arseanl two-foot contour map of the plants area, aerial photos of the South Plants on the scale one-inch to 100-feet, and by extensive visual inspection and on-the-ground mapping. All culverts and storm drainage conveyances in the plants were checked and flow observations were made during runoff events. Ten separate watersheds were identified in the South Plants area. Watershed boundaries were mapped and each watershed area was calculated. Watershed maps are included in Appendix A.

RAINFALL DATA

Rainfall data used in this study were taken from the Urban Storm Drainage Criteria Manual [8]. This manual provides rainfall isohyetal maps which give the depth of the precipitation in inches for 2, 5, 10, 25, and 100 year storm frequencies for a storm of 24 hours or other desired duration. The maps cover a six county area surrounding metro Denver from Longs Peak to Palmer Lake and from Deer Trail to the Continental Divide. The rainfall data in the manual is widely used in the Denver area and the reliability of the isohyetal lines has been satisfactory for design purposes for many years. An example of a rainfall isohyetal map covering the Arsenal is given in Figure 1.

Using the Urban Storm Drainage Criteria Manual procedures, precipitation data was extrapolated to represent the southern portion of the Rocky Mountain Arsenal in Section 1, Township 2 South, Range 67 West. From this data a Depth-Duration-Frequency graph was constructed to specifically represent this area (Figure 2).

100 YEAR

24 HOUR RAINFALL

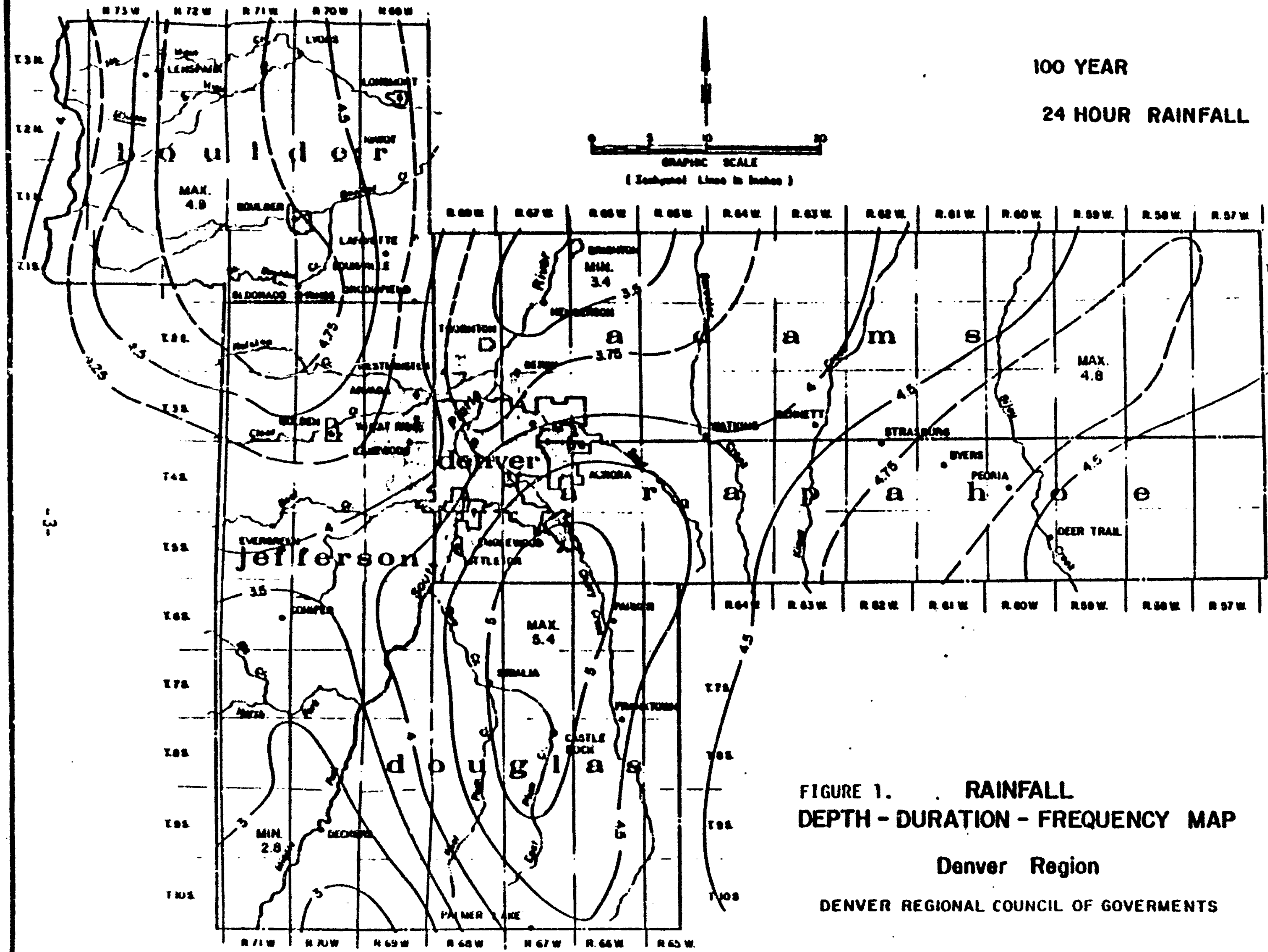
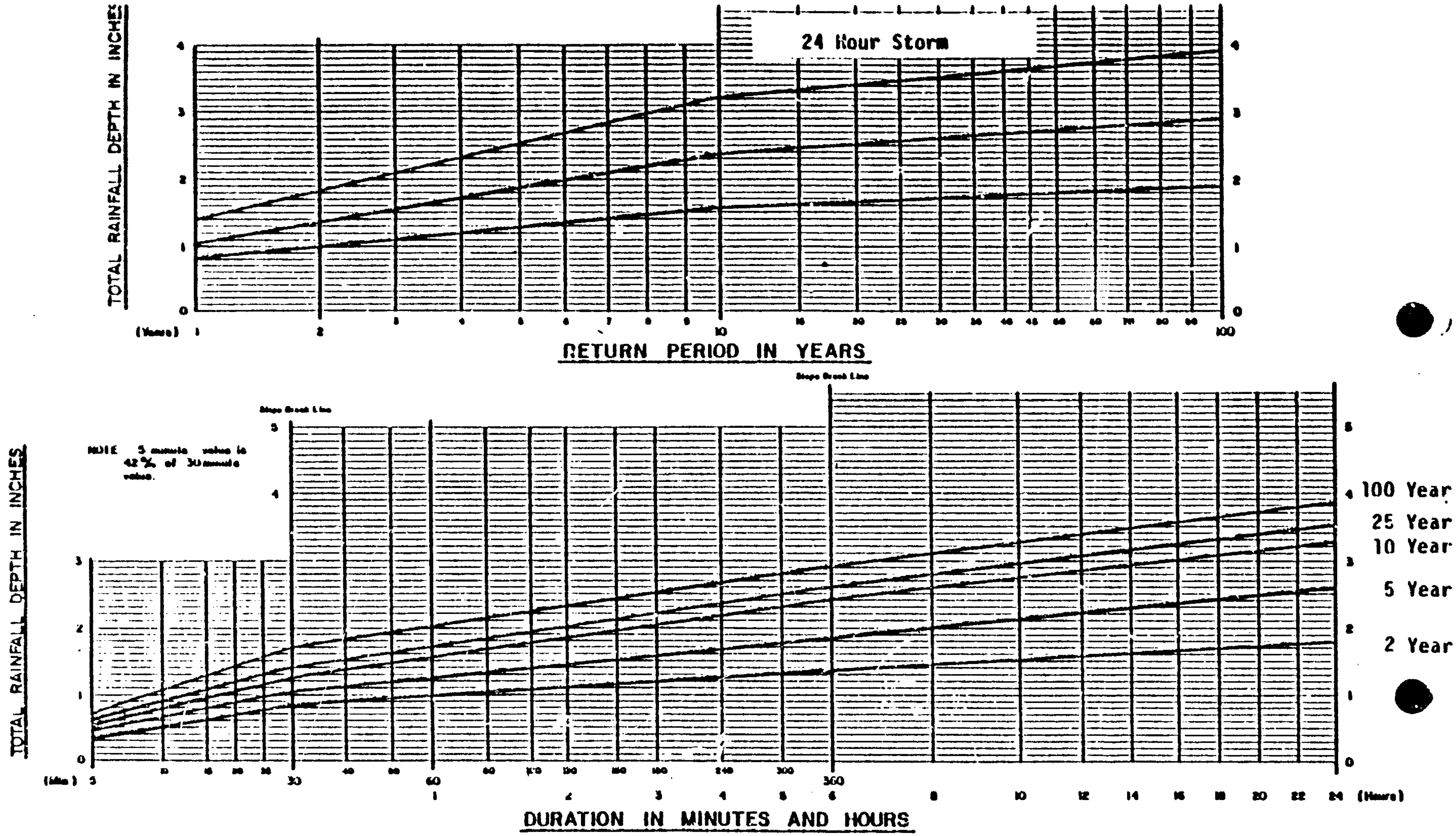


FIGURE 1. RAINFALL
DEPTH - DURATION - FREQUENCY MAP

Denver Region

DENVER REGIONAL COUNCIL OF GOVERMENTS



DENVER REGIONAL COUNCIL OF GOVERMENTS

Section 1, T. 25, R. 67 W.

FIGURE 2. RAINFALL
DEPTH-DURATION-FREQUENCY GRAPHS

Denver Region

Storm data from this graph used in this study are summarized below:

Frequency	Duration	Depth
2 year	24 hour	1.90 inches
5 year	24 hour	2.57 inches
10 year	24 hour	3.23 inches
25 year	24 hour	3.48 inches
100 year	24 hour	3.87 inches

Figure 3 and Table 1 present Time-Intensity Frequency Curve data for the 2-year, 10-year, and 100-year storms for Rocky Mountain Arsenal South Plants. This figure represents the most intense rainfall hour during a 24-hour storm.

For design purposes a storm pattern must be assumed in all hydrologic studies. The US Soil Conservation Service (1973) [3] has adopted a method where two patterns, Type I and Type II, are used. In this study the Type II storm pattern, applicable to this geographic area, is used. An example of the Type II storm is shown in Figure 4. In the one hour Time-Intensity-Freqency Curves discussed in the above paragraph the most intense one hour rainfall would occur between the 11th and 12th hours of the 24 hour storm. For any design storm duration less than 24 hours the steepest part of the type II curve is selected for the design storm.

SURFACE STORAGE, INFILTRATION, AND RUNOFF

Considerations of surface storage in the south plants were taken for all areas where concrete, asphalt or earthen berms impound precipitation and exclude it from surface runoff. These areas were mapped for each watershed and the area of impoundments excluded from the watershed area. These impoundments are

TABLE 1.

TIME-INTENSITY-FREQUENCY CURVE DATA

2 YEAR STORM

Minutes	Rainfall Depth	Intensity Inch/Unit Time	Per Hour	Intensity Inches/Hour
5 (.42)	.34	.34/5 Min	12	4.08
10 (.63)	.52	.18/5 Min	6	3.12
20 (.84)	.69	.17/10 Min	3	2.07
30	.82	.13/10 Min	2	1.64
40	.90	.08/10 Min	1.5	1.35
50	.96	.06/10 Min	1.2	1.15
60	1.00	.04/10 Min	1.0	1.00

10 YEAR STORM

5	.51	.51/5 Min	12	6.12
10	.77	.26/5 Min	6	4.62
20	1.02	.25/10 Min	3	3.06
30	1.22	.20/10 Min	2	2.44
40	1.32	.10/10 Min	1.5	1.98
50	1.41	.09/10 Min	1.2	1.69
60	1.50	.09/10 Min	1.0	1.50

100 YEAR STORM

5	.64	.64/5 Min	12	7.68
10	.96	.32/5 Min	6	5.76
20	1.28	.32/10 Min	3	3.84
30	1.52	.24/10 Min	2	3.04
40	1.68	.16/10 Min	1.5	2.52
50	1.79	.11/10 Min	1.2	2.15
60	1.90	.11/10 Min	1.0	1:90

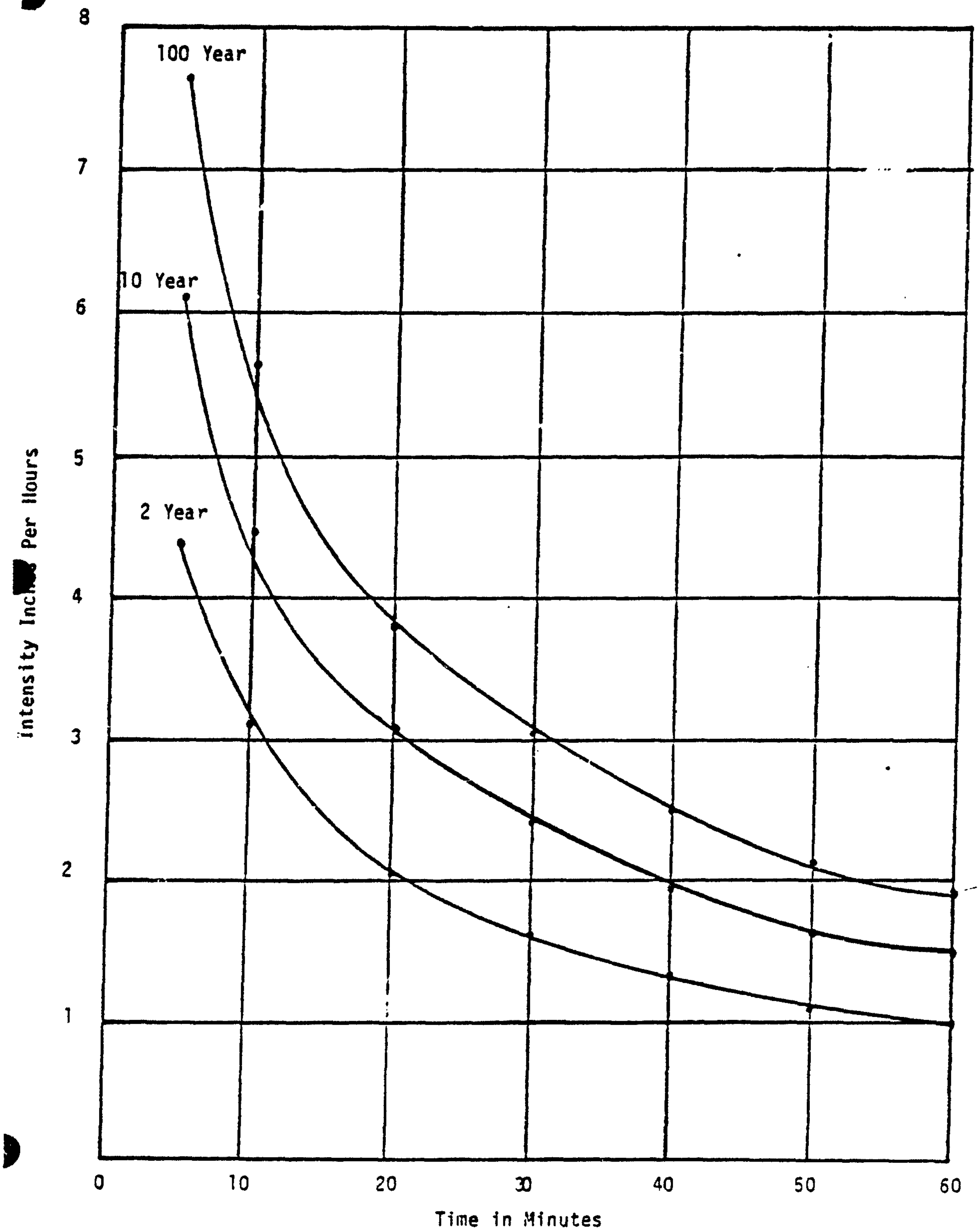


FIGURE 3. TIME - INTENSITY - FREQUENCY CURVE GRAPH

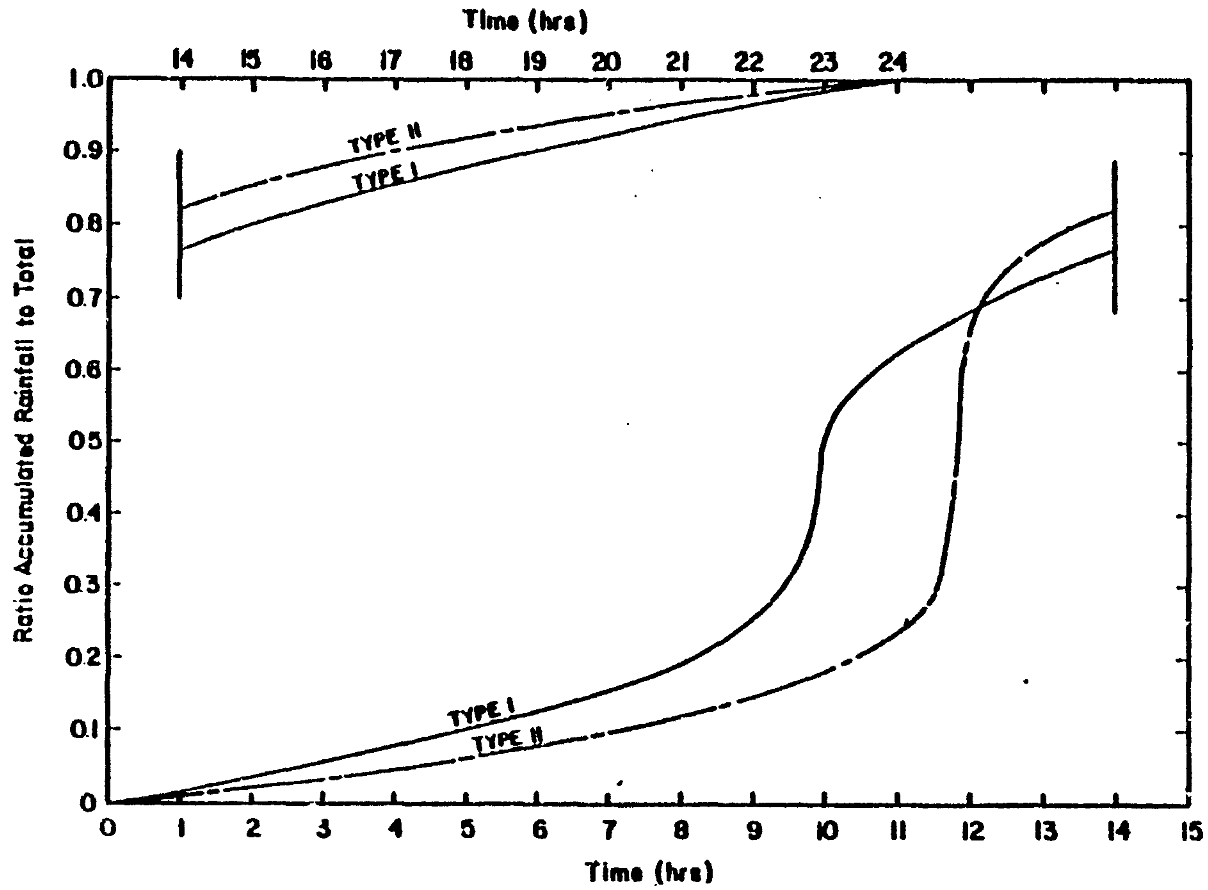


FIGURE 4. Twenty-four hour rainfall distribution. (SCS)

generally found as lagoons or enclosures around chemical storage tanks in the plants area. Precipitation is held in these structures until it evaporates.

The major abstraction from precipitation on the South Plants is infiltration into soils and structures. The critical factor affecting infiltration rates is the antecedent moisture condition. Generally wet soils and surfaces in the plants area have a lower infiltration rate than dry ones. Runoff calculations in this study were performed under three antecedent moisture conditions.

The method used for runoff calculations was developed by the Soil Conservation Service (SCS) of the US Department of Agriculture (1972) [8]. The method combines infiltration losses with surface storage and estimates rainfall excess, or equivalently, the runoff volume. The SCS method used assigns each soil type to a hydrologic Soil Group and each land use a curve number (CN) as detailed in Figure 5. The South Plants soils fall in Hydrologic Group B. For example, impervious areas are assigned a CN of 98, while pasture land in good condition is assigned a number of 61. In areas such as the South Plants where several land use types are evident, a weighted curve number (CN) is developed by mapping the acreage of each land use type, assigning a curve number from Figure 5, and calculating the weighted average CN.

A weighted curve number, CN, was calculated for each of the ten South Plants watersheds from the watershed maps. Maps were prepared using 1 inch to 100 feet scale aerial photographs of the South Plants and by field mapping as required to determine the actual type of land surface. The SCS curve number charts, (SCS, 1972) [8], Figure 5 were used to assign curve numbers. All areas in the South Plants were measured and no estimates were used. The Adams County, Colorado, soil survey [8] was used to identify the soils in the South Plants area. The Ascalon series

LAND USE DESCRIPTION	HYDROLOGIC SOIL GROUP			
	A	B	C	D
Cultivated land[1/]: without conservation treatment	72	81	88	91
: with conservation treatment	62	71	78	81
Pasture or range land: poor condition	68	79	86	89
good condition	39	61	74	80
Meadow: good condition	30	58	71	78
Wood or Forest land: thin stand, poor cover, no mulch	45	66	77	83
good cover[2/]	25	55	70	77
Open spaces, lawns, parks, golf courses, cemeteries, etc.				
good condition: grass cover on 75% or more of the area	39	61	74	80
fair condition: grass cover on 50% to 75% of the area	49	69	79	84
Commercial and business areas (85% impervious)	89	92	94	95
Industrial districts (72% impervious).	81	88	91	93
Residential:[3/]				
Average lot size — Average % Impervious[4/]				
1/8 acre or less — 65	77	85	90	92
1/4 acre — 38	61	75	83	87
1/3 acre — 30	57	72	81	86
1/2 acre — 25	54	70	80	85
1 acre — 20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[5/]	98	98	98	98
Streets and roads:				
paved with curbs and storm sewers[5/]	98	98	98	98
gravel	76	85	89	91
dirt	72	82	87	89

1/ For a more detailed description of agricultural land use curve numbers refer to National Engineering Handbook, Section 4, Hydrology, Chapter 9, Aug. 1972.

2/ Good cover is protected from grazing and litter and brush cover soil.

3/ Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

4/ The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

5/ In some warmer climates of the country a curve number of 95 may be used.

FIGURE 5. SCS Runoff Curve Numbers

dominates the plants area. Briefly described, this soil is loamy sand, and sandy loam, SM or SC, with permeability of 0.63 - 2.0 in the 0-21 inch horizon. These soils are in hydrologic soil type B and are generally described as having a moderate infiltration when thoroughly wet. They are chiefly moderately deep, well drained soils of moderately fine to moderately coarse texture. South of the plants the Truckton soil series occurs, but only in minor amounts in the watershed areas considered.

To represent differing degrees of soil moisture that can occur prior to a given storm the SCS method has developed a coefficient to convert curve numbers (CNs) representing a normal antecedent moisture condition II (AMC II) to drier condition (AMC I) and a wetter condition (AMC III). Curve numbers from the South Plants watersheds were converted via the SCS coefficient to represent the range of moisture conditions prior to the design storm event. Table 2 gives the curve numbers for the three different antecedent moisture conditions.

Once the weighted CN's are developed for each watershed, the SCS in Figure 6 provide experimentally derived solutions to the runoff equation. This figure allows the direct rainfall from each design storm to be converted to direct runoff in inches. For example, for a 100-year, 24-hour storm with a rainfall of 3.87 inches on watershed 4 with CN of 83, the direct runoff in inches is 2.20. Table 3 gives the direct runoff in inches for three antecedent moisture conditions for five design storms for the South Plants watersheds.

After the direct runoff in inches is graphically determined for each watershed, that value is multiplied by the watershed area in acres to determine the storm runoff volume for each design event in acre feet. These values are summarized in Table 4.

TABLE 2.

CURVE NUMBERS FOR THREE DIFFERENT
ANTECEDENT MOISTURE CURVES

Watershed	AMC II CN	Factor	AMC I	Factor	AMC III
1	85	.835	71	1.11	94
2	84	.822	69	1.11	93
3	88	.854	75	1.08	95
4	83	.814	67	1.12	93
5	72	.742	53	1.20	86
6	73	.748	55	1.19	87
7	77	.832	64	1.16	89
8	77	.832	64	1.16	89
9	84	.822	69	1.11	93
10	71	.736	52	1.20	85

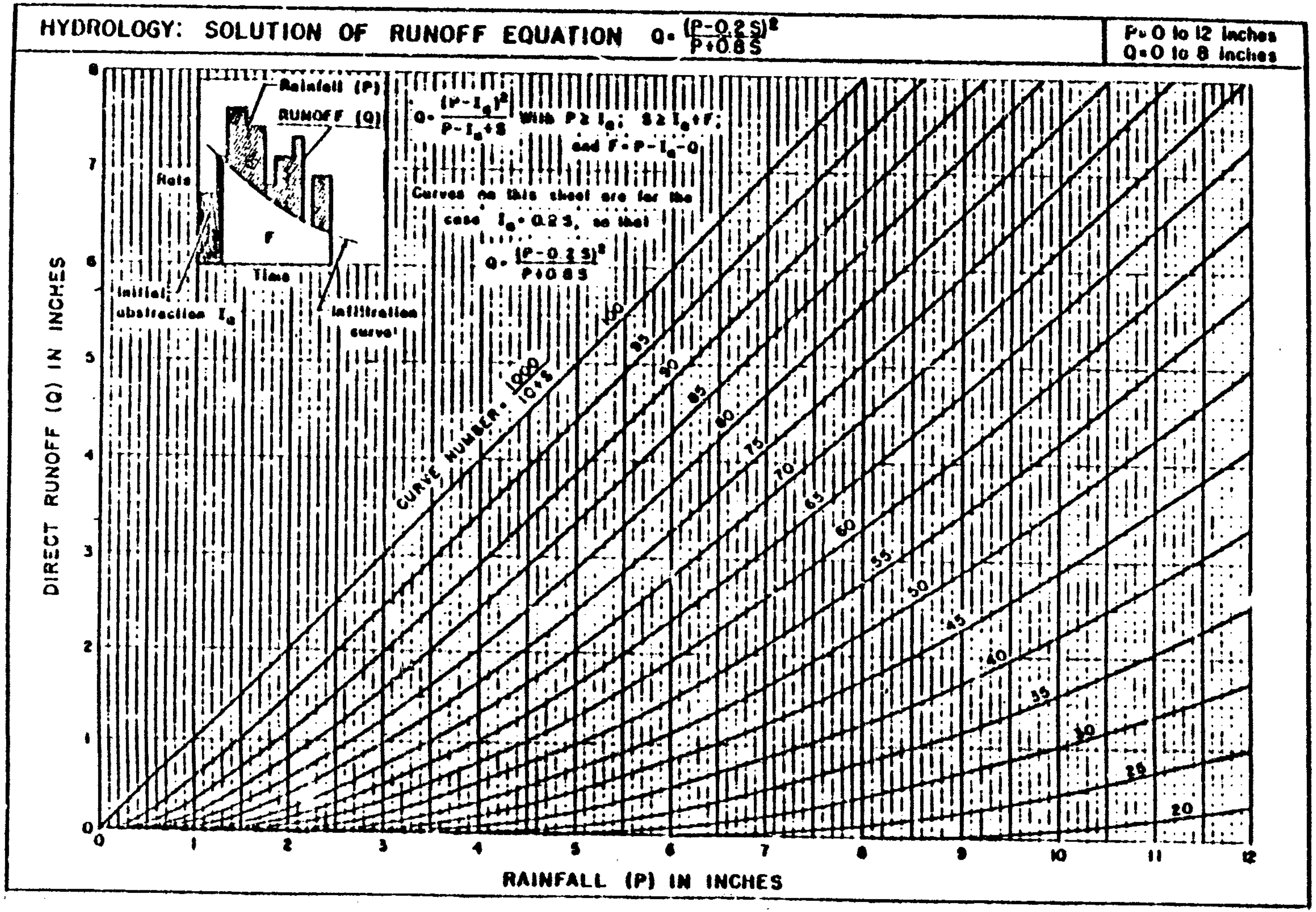


FIGURE 6. SOLUTION TO THE RUNOFF EQUATION

TABLE 3.

DIRECT RUNOFF IN INCHES FOR THREE ANTECEDENT MOISTURE CONDITIONS FOR DESIGN STORMS IN SOUTH PLANTS WATERSHEDS

Watershed Number	AMC I 24-Hour Storm Frequency					AMC II 24-Hour Storm Frequency					AMC III 24-Hour Storm Frequency				
	2	5	10	25	100	2	5	10	25	100	2	5	10	25	100
1	.21	.52	.90	1.10	1.25	.71	1.17	1.80	2.0	2.36	1.38	2.0	2.6	2.9	3.30
2	.19	.48	.80	.98	1.20	.65	1.10	1.70	1.90	2.28	1.36	1.90	2.50	2.80	3.10
3	.34	.70	1.12	1.30	1.60	.90	1.40	2.05	2.23	2.70	1.40	2.05	2.70	2.95	3.20
4	.12	.40	.70	.85	1.10	.59	1.08	1.60	1.80	2.20	1.36	1.90	2.50	2.80	3.10
5	0	0	.21	.26	.37	.22	.50	.95	1.0	1.40	.75	1.30	1.80	2.10	2.45
6	0	.10	.25	.32	.50	.23	.54	1.0	1.1	1.50	.80	1.38	1.90	2.20	2.60
7	.10	.30	.57	.70	.90	.41	.73	1.23	1.35	1.75	.96	1.50	2.20	2.30	2.70
8	.10	.30	.57	.70	.90	.41	.73	1.23	1.35	1.75	.96	1.50	2.20	2.30	2.70
9	.19	.48	.80	.98	1.20	.65	1.10	1.70	1.90	2.28	1.36	1.90	2.50	2.80	3.10
10	0	0	.19	.25	.35	.21	.48	.90	1.10	1.30	.70	1.25	1.80	2.00	2.35

PEAK FLOWS IN SOUTH PLANTS WATERSHEDS

The maximum flow volume in cubic feet per second was determined for each South Plants watershed for a full range of precipitation events and antecedent moisture conditions. Hydrographs were not developed at this point in the study because peak flow calculations are sufficient for sizing structures during design for small, simple watersheds. Peak runoff rates were estimated using the SCS-TR55 method (SCS, 1973) 0. In developing this method the SCS applied their Type II storm to a one-square-mile watershed using a CN of 75, sufficient rainfall volume to produce three inches of runoff, and a wide range of times of concentration. A computational computer program procedure was used to develop hydrographs using the regular SCS hydrograph procedure. As a result of the computer computations the SCS produced a curve relating time of concentration in hours to peak discharge, qp,' in cubic feet per second, per square mile, per inch of runoff.

Figure 7 gives this relationship. The time of concentration, tc, is the time it takes for flow to reach the basin outlet from the hydraulically most remote point on the watershed. Several methods are available for estimating the time of concentration for a watershed. A simple method for estimating time of concentration, tc, was used in this study. This method developed by the SCS 0 relates the time of concentration to the watershed lagtime as follows:

$$t_L = 0.6\ t_c$$

where t_L is the watershed lagtime in hours.

The SCS lagtime equation for t_L compatible with the curve number method used previously is

$$\frac{t_L = L^{0.8}\ (S + 1)^{0.7}}{1900\ Y^{0.5}} \qquad (50 \leq CN \leq 95)$$

where L is the hydraulic length of the watershed in feet, Y is the average land slope in percent for each watershed, and S is given by the equation:

$$S = \frac{1000}{CN} - 10$$

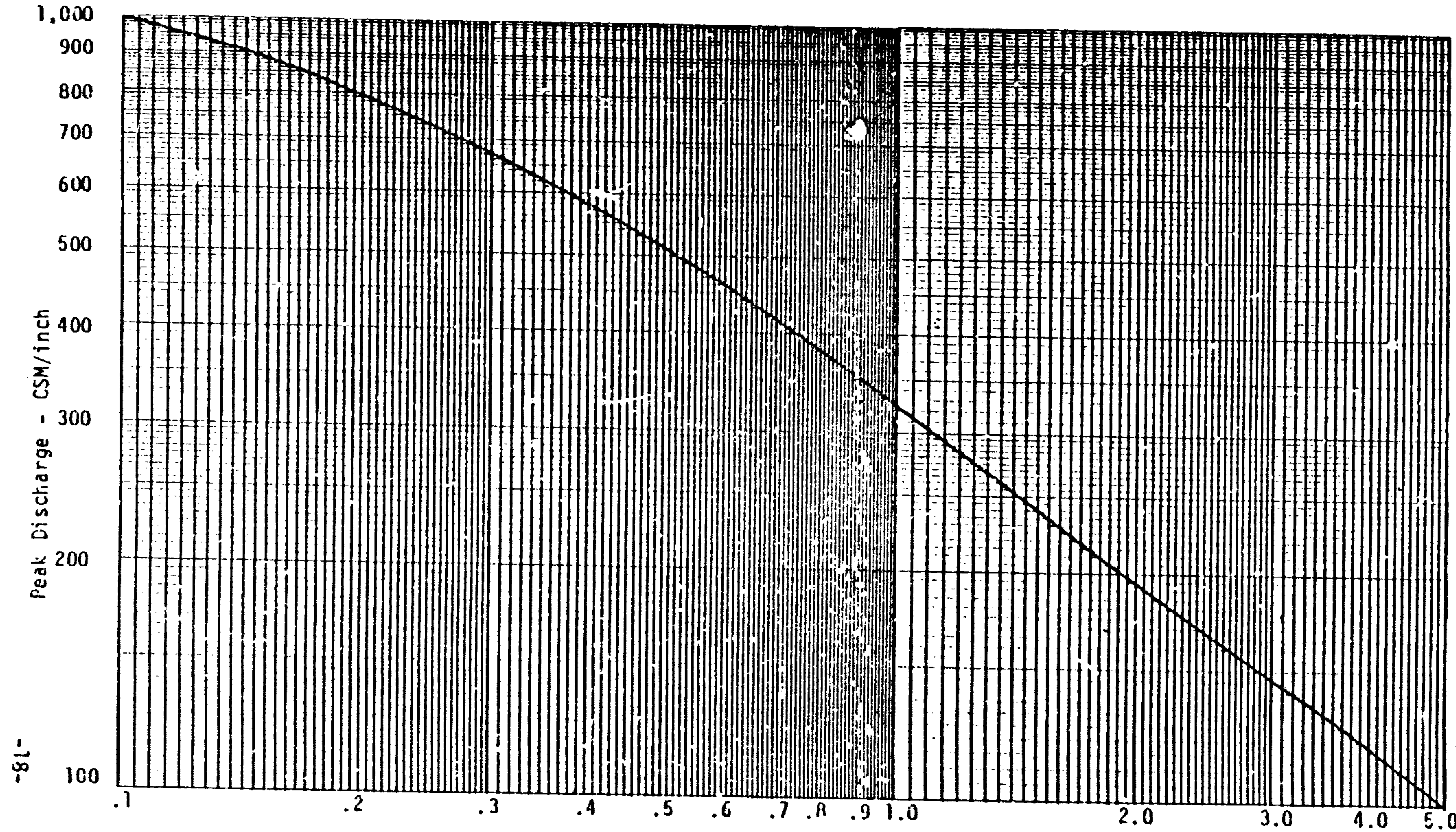
The curve number, CN, was calculated in the previous section. Data for the hydraulic lengths and slopes of the ten South Plants watersheds were calculated from two-foot contour maps on the 1" = 100 ' scale.

Once the time of concentration, tc, is calculated Figure 6 gives qp', cubic feet per second, per square mile, per inch of runoff. The peak flow is thus:

$$qp = qp' \quad AQ$$

where A is the watershed area in square miles, and Q is the runoff volume in inches from Figure 5.

Peak flows data for the South Plants watersheds are summarized in Table 5.



PEAK DISCHARGE IN CUBIC FEET PER SECOND PER SQUARE MILE
PER INCH (CSM/INCH) VERSUS TIME OF CONCENTRATION IN HOURS
FIGURE 7.

TABLE 4.

STORM RUNOFF VOLUME IN ACRE-FEET FOR THREE ANTECEDENT MOISTURE CONDITIONS FOR DESIGN STORMS ON SOUTH PLANTS WATERSHEDS

Watershed	ANC I 24-Hour Storm Frequency					ANC II 24-Hour Storm Frequency					ANC III 24-Hour Storm Frequency				
	2	5	10	25	100	2	5	10	25	100	2	5	10	25	100
1	.30	.74	1.28	1.57	1.78	1.01	1.67	2.56	2.85	3.36	1.96	2.85	3.70	4.13	4.70
2	.27	.67	1.12	1.37	1.68	.91	1.54	2.38	2.66	3.19	1.90	2.66	3.50	3.92	4.34
3	.31	.63	1.01	1.17	1.44	.81	1.26	1.85	2.01	2.43	1.26	1.85	2.43	2.67	2.89
4	.53	1.79	3.11	3.78	4.90	2.62	4.80	7.11	8.00	9.78	6.05	8.45	11.11	12.45	13.78
5	0	0	.33	.41	.58	.35	.79	1.50	1.58	2.21	1.18	2.05	2.84	3.31	3.87
6	0	.83	2.07	2.68	4.13	1.90	4.46	8.26	9.09	12.39	1.26	2.17	3.0	3.47	4.10
7	.02	.06	.12	.15	.19	.09	.15	.26	.28	.37	.20	.32	.46	.48	.57
8	.09	.28	.54	.66	.85	.39	.69	1.16	1.27	1.65	.91	1.42	2.08	2.17	2.55
9	.18	.45	.75	.92	1.13	.43	.72	1.12	1.25	1.50	.89	1.25	1.64	1.84	2.04
10	0	0	.12	.15	.21	.13	.29	.55	.67	.79	.43	.77	1.10	1.23	1.44

TABLE 5.

MAXIMUM FLOW RATES IN CUBIC FEET PER SECOND (CFS)

FOR THREE ANTECEDENT MOISTURE CONDITIONS FOR DESIGN STORM ON

SOUTH PLANTS WATERSHEDS

	AMC I 24 Hour Storm Frequency					AMC II 24 Hour Storm Frequency					AMC III 24 Hour Storm Frequenc				
Watershed	2	5	10	25	100	2	5	10	25	100	2	5	10	25	100
1	1.46	3.60	6.25	7.63	8.68	4.93	8.12	12.49	13.88	16.38	9.58	13.88	18.04	20.13	22.90
2	1.63	4.28	7.13	8.73	10.69	5.79	9.80	15.15	16.93	20.31	12.12	16.93	22.28	24.95	27.62
3	2.64	5.43	8.70	10.1	12.43	6.99	10.69	15.93	17.33	20.98	12.47	18.27	24.06	26.28	28.51
4	2.70	9.01	15.76	19.14	24.77	13.29	24.32	36.03	40.54	49.54	30.63	42.79	56.30	63.06	69.81
5	0	0	3.37	4.19	5.92	2.25	5.11	9.70	10.21	14.29	7.66	29.28	40.54	47.29	55.17
6	0	2.94	7.36	9.42	14.72	6.77	15.39	29.43	32.37	44.15	23.54	31.08	42.79	49.54	58.55
7	.20	.60	1.13	1.39	1.79	.82	1.45	2.45	2.69	3.48	1.91	2.99	4.38	4.58	5.37
8	.64	1.91	3.63	4.46	5.73	2.61	4.55	7.84	8.60	11.15	6.12	9.56	14.01	14.65	17.20
9	.65	1.65	2.75	3.37	4.13	2.24	3.78	5.85	6.54	7.84	4.68	6.54	8.60	9.63	10.66
10	0	0	.62	.81	1.14	.68	1.56	2.93	3.25	4.23	2.28	4.06	5.85	6.50	7.64

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